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A study of consumer benefit from district heating service in Korea

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ABSTRACT

Integrated energy supply (IES) produces both heat and electricity simultaneously, improving energy efficiency and reducing air pollutants. As of the end of 2016 in Korea, 16.1% of households received district heating service as the government pushed to expand the integrated energy supply. Since large-scale facilities are installed according to local demand for heat, IES—compared to individual heating systems—can increase the consumer benefit by reducing the annual cost of heating through lower facility costs. This study estimates the consumer benefits of district heating service from IES. We apply the compensated variation (CV) based on the Hicksian welfare concept and evaluate new consumers as well as existing consumers who switch from individual heating to district heating. The estimated CV shows that the new consumer benefit is 1.75 times higher in terms of heating cost if they use district heating from IES; moreover, they benefit 50% more than the Marshallian consumer surplus. Consumers who switch to district heating gain a 24% benefit (economic value/heat price equals 1.24). Electricity produced from IES is an indispensable energy source for industrial production, household appliances, cooking, and lighting and the estimated CV shows that a consumer who uses one unit of electricity enjoys 1.38 times additional benefit.

1. Introduction

The Integrated energy supply (IES) describes the business of providing numerous users, residential, commercial, and industrial complexes, with energy (heat or heat and electricity) produced from combined heat and power plants (CHP) or heat-only boilers facilities in given areas. It is subdivided into district heating that supplies heating or heat and electricity to households and stores and integrated energy that supplies heat and electricity to industrial complexes.

IES includes energy usage reduction and improvement in the atmospheric environment as it is more efficient to use CHP facilities to produce electricity and supply heat from waste heat generated in this process than producing heat and electricity independently. While the total efficiency from producing heat and electricity using individual facilities is 49.9%, the efficiency from CHP is 80.7%.

The IES business provides national benefits by increasing energy efficiency and reducing energy usage and greenhouse gas emission (i.e., CO2). The Korean government set its 2030 target of reducing greenhouse gas emission by 37% from business-as-usual levels. It led to the creation in 2010 of an implementation plan to reduce greenhouse gas emissions, which included the expansion of IES.

The Korean government has been pushing to expand the IES through the enactment of the intergraded energy supply act. When businesses, such as house construction, lot development, and industrial complexes, flourish, the Korean government requires that the feasibility of IES service is discussed. Every five years, the new supply plan for district heating is established through a basic plan for integrated energy supply. The Korea District Heating Corporation, established in 1985, has led the efficient implementation of IES supply. As of 2016, a total of 73 firms, including public and private ones, were supplying a total of 2.695 million households from a total of 103 businesses locations, accounting for 16.1% of the total number of households in Korea.

For consumers, the heat supply using IES provides benefits as well: by installing large-scale facilities in accordance with local demand for heat, it can reduce the annual heat cost compared to individual heating systems through lower facility costs; further, it can increase industrial business competitiveness by supplying high-quality heat and electricity to industrial complexes. Accordingly, the Korean policy makers thus need information on the benefits of providing district heating service in the region.

The study of consumer benefits from the district heating service in Korea has been limited (Korea District Heating Corporation, 2015). Further, it has been estimated often using the Marshallian demand function derived from the consumer utility maximization. This

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Table 1
Permission and supply status of IES business (2016).
Source: A Handbook of integrated energy system business (2017), Korea Energy Agency

Categories	Number of business operators	Number of business sites	Supply		Installed capacity	
			Number of households	Number of businesses	Heat (Gcal/h)[a]	Electricity (MW)
District heating	31	59	2,618,264	–	17,659.5	5498.5
Industrial complex	36	38	–	835	14,219.5	2410.1
Parallel	6	6	76,412	73	2021.3	929.8
Total	73	103	2,694,676	908	33,900.3	8838.3

Note
[a] ton/h is converted to Gcal/h uniformly (1 ton/h = 0.539 Gcal/h).

approach is conditional on the consistency of the marginal utility of the consumer's income: in other words, it hypothesizes that the heat demand of district heating and the heat demand of individual heating increase at a certain rate as income increases because consumption and the substitute good increase at a certain rate as income increases.

This study estimates the benefit of the supply of heating from IES using the Hicksian welfare concept through the compensated demand function derived from the cost minimization under the assumption that the consumer utility remains constant. In addition, although the total consumer surplus from the supply of district heating has been studied, IES includes not only the supply for new consumers but also for existing consumers who switch from individual heating to district heating; this study estimates the benefits for both types of customers.

The structure of this study is as follows: Section 2 explains the current situation of the IES in Korea; Section 3 reviews the theoretical aspects of consumer benefits and examines the estimation methodology; Section 4 explains the empirical data, estimates the Hicksian demand function based on econometric methods, and computes the consumer welfare; Section 5 presents our conclusions and implications.

2. Current situation of the IES business in Korea

In general, the IES business is divided into two types: district heating and industrial complex. However, because some firms operate both types of businesses simultaneously, the business, as of 2012, has been categorized into three types including the type where both are operated in “parallel”. At the end of 2016, a total of 73 firms including public and private ones, have been supplying a total of 2.694 million households from a total of 103 businesses locations, accounting for 16.1% of 16.692 million households, the total number of households in Korea (see Table 1).

At the end of 2016, the installed capacity of the IES business was 33,900 Gcal/h of heat and 8,838 MW of electricity. Of this, the district heating sector accounted for 17,659 Gcal/h of heat and 5,498 MW of electricity and industrial complex accounted for 14,219 Gcal/h of heat and 2,410 MW of electricity. The “parallel” sector accounted for 2,021 Gcal/h of heat and 929 MW of electricity.

The district heating sector includes district cooling. At the end of 2016, 27 businesses (24 district cooling business operators and 3 “parallel” business operators) were supplying district cooling to 1151 buildings and the refrigeration machine capacity supplied was 750,818usRT.

As of the end of 2016, the total amount of fuel usage at IES business sites was 14.23 million toe, accounting for 4.8% of Korea's primary energy consumption (295.67 million toe). District heating, industrial complex, and “parallel” sectors accounted for 5.28 million toe, 7.69 million toe, and 1.26 million toe, respectively. The fuel usage of co-generation CHP accounted for 77.2% of the total fuel usage and the heat only boilers accounted for only 17.2% (see Table 2).

Out of total heat production of 92.45 million Gcal, the heat from own-production facilities accounted for 85.1% and outside heat for 14.9%. The heat produced from own-production facilities was 78.70 million Gcal. In terms of each sector, district heating accounted for 12.73 million Gcal, industrial complex for 60.73 million Gcal, and “parallel” for 5.23 million Gcal. Out of 21.96 million Gcal, which was the total heat production of the district cooling and heating sector, CHP produced 43%, and heat-only boilers 13.6%. Out of 64.71 million Gcal, which was the total heat production of the industrial complex sector, CHP produced 70.2%, and heat-only boilers 18.6%.

Table 2
Fuel used by type of facility (2016).
Source: A Handbook of integrated energy system business (2017), Korea Energy Agency

Categories	Fuel usage (TOE)			total
	CHP	heat only boiler	others*	
District heating [a]	3,987,440	495,798	802,527	5,285,766
Industrial complex	5,902,250	1,789,145	226	7,691,621
Parallel	1,096,481	165,319	–	1,261,800
Total	10,986,171	2,450,262	802,754	14,239,187
Ratio (%)	77.2	17.2	5.6	100.0

Note
[a] District heating includes fuel cells, heat pumps, ice storage tanks, and absorption refrigerating machines. For industrial complexes, this indicates the heat from internal processes.

The amount of outside heat supplied from incineration plants was 13.74 million Gcal. In terms of each sector, district heating accounted for 9.22 million Gcal, industrial complex for 3.98 million Gcal, and “parallel” for 0.53 million Gcal (see Table 3).

The electricity produced directly from the IES business was 39,041 GWh, which accounted for 7.38% of Korea's power generation (528,837 GWh). Out of total electricity production, own-production accounted for 81.2% and the Korea Electric Power Corporation accounted for 18.8%. In terms of own-production by sector, district cooling and heating accounted for 20,400 GWh (96% of total electricity production), industrial complex for 13,627 GWh (62.5%), and the “parallel” sector for 5012 GWh (99.5%) (see Table 3). The amount of electricity provided by the Korea Electric Power Corporation was 9053 GWh, of which 850 GWh was provided for district heating, 8177 GWh to the industrial complex sector, and 25 GWh to the “parallel” sector.

According to data from the Korea Energy Agency,[1] LNG and coal, in terms of fuel usage, had the largest shares with 37.4% and 29.4%, respectively. For district heating operators, the majority of energy usage, 79.5%, was LNG, compared to 4.7% for industrial complex operators and 60.4% for “parallel” operators. For industrial complex operators,

[1] A Handbook of integrated energy system business (2017), Korea Energy Agency.

Table 3
Heat and electricity production from IES in 2016.
Source: A Handbook of integrated energy system business (2017), Korea Energy Agency

Categories	Heat production (Gcal)						Electricity Production (MWh)		
	Own-production				Outside heat supplied[b]	Total	Own-Production	Korea Electric Power Generation	Total
	CHP	Heat only	Others[a]	Sub-total					
District heating	9,440,766	2,977,208	318,694	12,736,668	9,228,657	21,965,325	20,400,370	850,679	21,251,049
Industrial complex	45,401,774	12,038,324	3,291,569	60,731,667	3,981,562	64,713,229	13,627,955	8,177,704	21,805,659
Parallel	5,165,001	72,261	1170	5,238,432	534,747	5,773,179	5,012,455	24,938	5,037,393
Total	60,007,541	15,087,793	3,611,433	78,706,767	13,744,966	92,451,733	39,040,780	9,053,321	48,094,101
Ratio (%)	64.9	16.3	3.9	85.1	14.9		81.2	18.8	100.0

Note
[a] Others: cell fuels, heat pumps, turbo-refrigerating machines, ice storage tanks, absorption refrigerating machines, solar energy, waste energy from internal process.
[b] Outside heat supplied from incineration, waste heat from plants, waste heat from external processes (excluding annual heat exchange between business operators).

Table 4
Trends in heat and electricity facilities of Korea District Heating Corporation.
Source: Internal Data, Korea District Heating Corporation

		2012	2013	2014	2015	2016	Annual growth rate
							2012–2016
Heat (Gcal/h)	Metropolitan area	7954	6239	7973	7034	6974	−3.2
	Others	984	1012	958	1094	1094	2.7
Electricity (MW)	Metropolitan area	1520	1520	1520	1522	1522	0.04
	Others	108	107	107	108	108	0.0

the majority of energy usage, 49.1%, was coal, while district heating operators did not use coal due to regulations on eco-friendly fuel in metropolitan areas. Out of total outside heat supplied, the heat generated by the incineration of waste accounted for 38.8% and heat generated by power plants for 37.1%. Out of 13.74 million Gcal, the total outside heat supplied, the district heating sector accounted for 67% or 9.22 million Gcal.

The Korea District Heating Corporation heat sales to households represented 60% of the IES operator sales. Moreover, it had 21 business sites, including those in metropolitan areas and, as of 2016, its heat supply facilities in metropolitan areas accounted for about 85% of its heat supply facilities in the country. Its facilities that supplied heat to metropolitan areas continued to grow through 2014, reaching 7979 Gcal/h. However, its supply declined to 6974 Gcal/h in 2016 due to a decrease in heat demand. However, its non-metropolitan areas grew at an annual rate of 2.7% from 2012 to 2016 due to expansion in new development areas (see Table 4). The Korea District Heating Corporation has an installed capacity of electricity supply of about 1.63 GW in total and 93% of this is located in metropolitan areas. The annual growth rate of installed capacity was stable at 0.04% in metropolitan areas and 0.0% in non-metropolitan areas from 2012 to 2016.

3. Consumer benefit from district heating service

3.1. Literature review

Estimates of consumer benefits are generally calculated based on the price a consumer is willing-to-pay for one unit of goods using the demand/price relationship in the demand function. In addition, for non-market goods (i.e., services and intangibles), there are techniques such as the revealed preference method that evaluates value using data from consumer behavior or the stated preference method that estimates value by asking consumers and eliciting responses. The estimation of consumer benefit through the demand function can be done using the Marshallian approach in which consumer surplus is estimated by examining the ordinary demand function derived from utility maximization. In addition, the Hicksian approach can be used where the compensating variation is estimated through the compensated demand function derived from the cost minimization while holding the utility constant.

By comparing quotes for online insurance premiums, Heo and Hong (2005) estimated the consumer surplus that insurance holders could enjoy in terms of economic value. They estimated the insurance demand function using variables including the insurance premium, prices of other goods, income, and consumer preferences, and calculated the consumer surplus through the ordinary demand function. The average consumer surplus was 231,050 won per contract and the ratio of economic value per price, including consumer surplus, was calculated as 1.54.

Cho et al. (2005) calculated the economic benefit to consumers from the introduction of competition in the telecommunications industry. They used data collected from online surveys of mobile phone subscribers to estimate demand for mobile calling. The call volume was determined by the per-minute call rate and other factors and the estimated demand function was used to calculate the consumer surplus through the Marshallian approach. The consumer surplus across the nation was estimated at 6.4261 trillion won and the ratio of economic value per price accounting for 11.9672 trillion won was calculated at 1.53.

Korea District Heating Corporation (2015) estimated the consumer utility for the IES business. They calculated the consumer benefit by deriving the ordinary demand function for consumer heat demand. The price elasticity of heat demand was estimated to be −0.7, and the consumer benefit was calculated at 154,800 won/Gcal through the ordinary demand function. The ratio of economic value per price was calculated at 1.71.

Lee et al. (2012) estimated the demand function for LPG for transportation and used price elasticity to estimate the consumer surplus and economic benefits that come from consuming LPG for transportation. The price elasticity was estimated to be −0.422 and, as of 2012, the

consumer surplus and economic value were 0.966 trillion won and 1.713 trillion won, respectively. The ratio of economic value per price was calculated at 2.19.

Kim et al. (2017) evaluated Korean household's willingness to pay for district heating system over individual heating system for residential heat. This study showed that average additional willingness to pay district heat over individual heat was 5.4USD/Gcal and customers had about 6% more benefits than district heating compared individual heating.

Brynjolfsson et al. (2003) estimated the consumer surplus for online book sales. They hypothesized that through online book sales, consumer surplus would increase due to the increased variety in consumer choice of books and the competition among existing bookstores. The consumer benefit was estimated using the compensating variation by Hausman and Leonard (2002). There was a 6% decrease in online sales prices when the price elasticity was between −1.56 and −1.79, and the consumer surplus was estimated to be 100.5 to 103.3 million dollars.

Waverman et al. (2016) estimated the consumer surplus that resulted from the introduction of competition in telecommunication services in Bahrain. The Hicksian approach was used to calculate the compensation variation. The consumer surplus in 2014 was estimated to be between 96 and 192 million Bahrain dinar (BD) when the price elasticity was between −0.5 and −1.0, which was about 0.75%–1.5% of GDP.

3.2. Model of consumer benefit

This study estimates the consumer benefit from district heating provided by IES. The benefit can be categorized into the benefit that the consumer gains from the new heat demand resulting from new housing developments and the benefit that comes from consumers switching from existing individual heating to IES. The benefit of the IES supply can be expressed as the difference in the cost functions between individual heating and district heating while the consumer's utility level prior to the introduction of IES remains the same:

$$\mathrm{CV} = E(P_{I0}, P_{D0}, U_0) - E(P_{I1}, P_{D1}, U_0) \tag{1}$$

where P_I is the price of individual heating, P_D is the price of district heating, P_{I0} and P_{D0} are the prices of individual and district heating prior to the introduction to the IES, respectively, P_{I1} and P_{D1} are the prices of each after the introduction of IES, respectively, U is the consumer's utility level before the introduction, and CV is the compensating variation. Compensating variation refers to the level of compensation that individual heating consumers' need after the supply of IES to maintain their prior utility level.

The following equation is obtained following the method of Hausman and Leonard (2002) in equation (1):

$$\mathrm{CV} = [E(P_{I1}, P_{D0}, U_0) - E(P_{I1}, P_{D1}, U_0)], +[E(P_{I0}, P_{D0}, U_0) - E(P_{I1}, P_{D0}, U_0)] \tag{2}$$

The first term in equation (2) is the Variety Effect (VE), which refers to the change in consumer utility in the district heating after the introduction of IES. The second term is the Price Effect (PE), which refers to the change in utility due to the actual change in the price of heating after the introduction of IES.

Since the price of individual heating does not include an actual price change after the introduction of IES, the price effect is zero, and only the VE exists. Hence, if $P_{I0} = P_{I1} = P_I$, then the CV can be represented as follows:

$$CV = E(P_I, P_{D0}, U_0) - E(P_I, P_{D1}, U_0) = E(P_{D0}, U_0) - E(P_{D1}, U_0) \tag{3}$$

Assuming that district heating is possible through the IES supply using equation (3), this study applies the function by Brynjolfsson et al. (2003) and hypothesizes that the consumer's heat demand function can be represented as the below log-linear function:

Table 5
The data analysis statistics.

	Unit	Obs.	Mean	Std. Dev.	Min	Max
Real price[a,b]	won/Gcal	120	65,154.11	15,022.15	38,678.26	109,690.7
Heat sales	Gcal	120	1,981,612	1,765,257	17,442	5,977,924
Real GDP[a b]	1 billion won	120	6,246,642	369,025.4	5,072,232	7,205,162

Note
[a] Deflated by 2010 GDP indicator.
[b] Korean won exchange rate against US dollar was 1160.5 in 2016.

$$Q(P, Y) = AP^{\alpha}Y^{\delta} \tag{4}$$

where Q is the heat demand, P is the price of heat for district heating, Y is income, α is price elasticity, δ is income elasticity, and A is a constant term.

By partially differentiating equation (4) into the indirect utility function that utilizes the Roy's identity, the following equation can be derived:

$$v(P, Y) = -A\frac{P^{1+\alpha}}{1+\alpha} + \frac{Y^{1-\delta}}{1-\delta}$$

The expenditure function can be expressed as follows:

$$E(P, U_0) = \left[(1-\delta)\left(U_0 + \frac{Ap^{1+\alpha}}{1+\alpha}\right)\right]^{1/(1-\delta)} \tag{5}$$

Using equations (3) and (5), the change in consumer benefit from the IES supply can be represented as the following equation (6):

$$CV = \left[\frac{1-\delta}{1+\alpha}Y^{-\delta}(P_I Q_0 - P_{D1}Q_1) + Y^{(1-\delta)}\right]^{1/(1-\delta)} - Y \tag{6}$$

where $P_{D1}Q_1$ is the heat price and demand after the IES supply and P_IQ_0 is the individual heating price and demand before the introduction.

If the district heating is supplied through the new housing development or industrial complex development, P_IQ_0 does not exist because it is the concept of creating the new demand rather than switching from existing individual heating to district heating. Hence, the CV can be represented as the following equation (7):

$$CV = \left[\frac{1-\delta}{1+\alpha}Y^{-\delta}(-P_{D1}Q_1) + Y^{(1-\delta)}\right]^{1/(1-\delta)} - Y \tag{7}$$

In 2017, among the total 2.694 million households that were supplied IES in Korea, 76,000 households represented the new demand from the IES development.

When estimating the CV, if the cost of district heating accounts for a small portion of the national economy or household income or if income is fixed within a certain period of time, the CV for the new demand and fuel replacement can be simplified into the following equations (8) and (9):

$$CV = -\frac{P_{D1}Q_1}{1+\alpha}, \tag{8}$$

$$CV = \frac{P_I Q_0 - P_{D1}Q_1}{1+\alpha} \tag{9}$$

4. Data and estimation

This study uses the following data: the Korea District Heating Corporation's quarterly performance (120 quarters) of heat production and sales prices (Korean won/Gcal) from 1988 to 2017 and real GDP quarterly data for the same period to obtain income elasticity.

In the 120 quarters, the real price of heat was around 65,000 won/Gcal (56USD/Gcal). The highest sales price was about 109,690 won and the lowest 38,678 won (see Table 5). The performance of heat

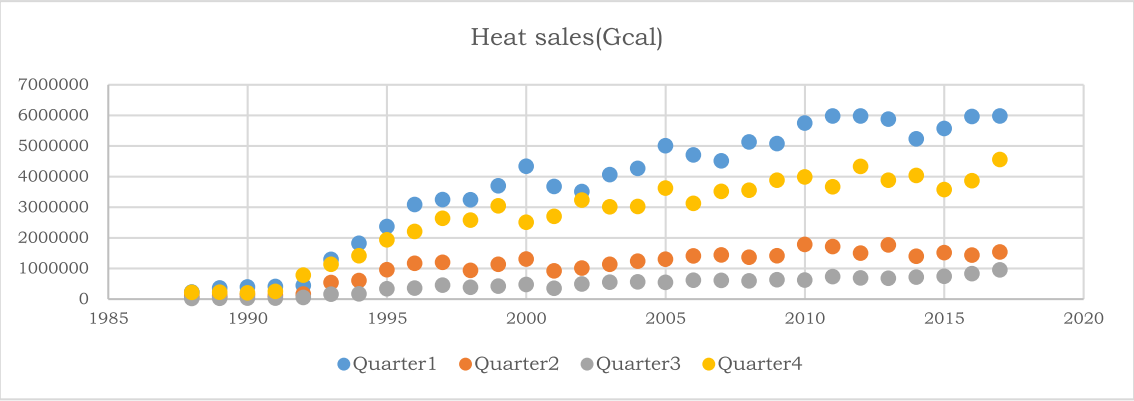

Fig. 1. Trend of heat demand.

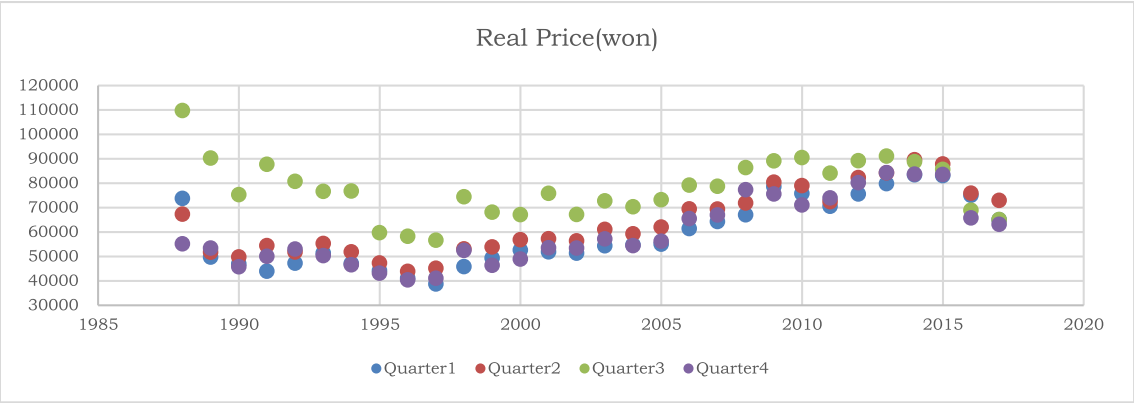

Fig. 2. Trend of real heat price.

production by the Korea District Heating Corporation shows a rapidly increasing trend. Heat sales increase from 17,422 Gcal in the third quarter of 1988 to 5,977,924 Gcal in the first quarter of 2012, growing more than 340 times.

Heat use varies with the weather, as change in temperature affect the demand for space heating. Heat demand in Korea is clearly shown to be seasonal as the demand is concentrated in the first and fourth quarters. It has both winter (first quarter) and summer (third quarter) peaks that can each ranges as large as about 5 million Gcal (see Fig. 1 and 2).

With the increasing number of households demanding IES—about a quadruple increase from 10.59 million households in 1995 to 39.69 million households in 2015—the difference in the heat demand between summer and winter grew. Also quarterly real GDPs are shown in Fig. 3.

4.1. District heat demand function

The following equation estimates Korea's district heat demand:

$$\log Q_t = \beta_0 + \beta_1 logP_t + \beta_2 logY_t + \beta_3 logQ_{t-1} + \beta_4 D_1 + \beta_5 D_2 + \beta_6 D_4 + \varepsilon_t \quad (10)$$

where the dependent variable, $logQ_t$, is the log of heat demand at time t, the independent variable, $logP_t$, is the log of the real heat price (Korean won/Gcal) at time t, $logY_t$ is the log of real income at time t, $logQ_{t-1}$ is the log of heat demand at t-1, and D_1, D_2, and D_4 are seasonal dummy variables representing 1st quarter, 2nd quarter, and 4th quarter, respectively.

The regression equation (10) was estimated through traditional ordinary least squares and the Huber-White standard error was estimated taking into account heteroscedasticity. The value of the Durbin-Watson test for auto-correlation between error terms was 2.44, showing that auto-correlation was insignificant in the regression (see Table 6). In order to use the lag variables from the quarterly data, we need to examine the stationarity of the time series; the Z(t) from the Dickey-Fuller Test was −5.909, which was lower than the 1% critical value (Z(t) = −3.504); hence, the null hypothesis was rejected at 99%, thereby satisfying the stationarity condition.

The results in Table 6 reveal that all variables are statistically significant at 1% level, meaning that the estimated values have 99% chance of being true, except the constant and income variable. The income variable was statistically significant at 10%. The estimated R^2 is 0.9762, implying that about 97.6% of the variance for a log of heat demand is explained by these defined independent variables.

The estimated values for the price and income variables represent price elasticity and income elasticity, respectively. The estimated coefficient for price is −0.433, indicating that heat demand decreases by 0.433% as the price increases by 1%. Heat is a utility good and consumers are less sensitive to its price. Given that the price elasticity of electricity, which is approximately the same utility good in Korea, is −0.3, the estimated price elasticity for heat seems to be appropriate.

At 90% confidence level, a 1% increase in income induces a 0.923% increase in heat demand. Per capita income in Korea has steadily increased over the years, except during the financial crisis in 1998. As the number of households switching to district heat has increased due to the expansion of the IES supply, the heating demand has increased as well, showing a positive relationship.

The seasonal dummy variables in district heat demand function account for the level change in the log of the heat demand given independent variables. That is even independent variables remained

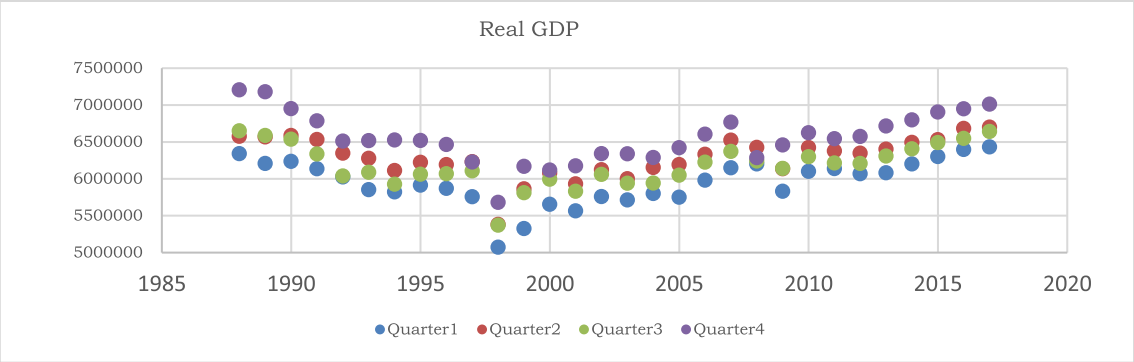

Fig. 3. Trend of real GDP[2].

Table 6
Estimation result of Korea's heat demand function.

	Coef.	Std. Err	t	P > |t|	[95% Conf. Interval]	
LogPt	−.4333492[b]	.1487392	−2.91	0.004	−.7280568	−.1386416
LogYt	.9239090[a]	.5038765	1.83	0.069	−.0744577	1.922276
Log Q t-1	.9950235[b]	.0397391	2504	0.000	.9162857	1.073761
D1	1.305419[b]	−0.662371	19.71	0.000	1.174178	1.436659
D2	−.3150322[b]	−.0850791	−3.70	0.000	−.4836055	−.146459
D4	2.683046[b]	0.781213	34.34	0.000	2.528259	2.837833
cons	−10.48458	7.16431	−1.46	0.146	−24.67974	3.710587

F(6,112) = 731.46, R-squared = 0.9762.
Whit's test: Chi2(21) = 63.58; Prob > Chi2 = 0.000.
Durbin-Watson D-statistic(7,119) = 2.4402.
Dickey Fuller test: −5.909.
[a] Significant at 10%.
[b] Significant at 1%.

unchanged, the log of heat demand have different value from quarter to quarter. Constant term changes are not caused by independent variables, but by seasonal factors. The estimated seasonal dummies for the first and fourth quarters show a significant increase in demand compared to the third quarter, the constant term. The second quarter estimate is expected to be lower than the third quarter; however, this is an unexpected result considering that the heat demand is actually higher in the second quarter than in the third quarter. This may be due to the effect from the value of the constant term −10 for the third quarter, the base quarter.

4.2. Consumer benefit from district heat service

The estimated values of the CV for new consumers from the heat supply using the estimated coefficients and equation (8) are presented in Table 7. To obtain the consumer benefit from the IES supply, we first need to have information on heat sales and prices. In 2016, the heat demand met by the Korea District Heating Corporation was 12,084,818 Gcal and the average sales price was 67.42USD/Gcal. These data were used as the values of $P_{D1}Q_1$ in estimating CV.

The CV using equation (8) and applying price elasticity of −0.433 was calculated as −1429.51 million USD in total, under the assumption that all consumers are new consumers and not the consumers who switched from individual heating. Since CV is the concept of the cost that consumers pay to maintain their prior utility level after the introduction of IES, the negative value (−) indicates the benefit from the introduction of district heating.

The CV per unit is 118.28USD/Gcal. When a new consumer uses the district heating after the introduction of IES, he or she pays 67.42USD/Gcal and obtains a 1.75 times additional benefit. The total economic value per unit of district heating is estimated to be 185.71USD/Gcal, which is the sum of the price per unit and the CV.

Typically, in the Marshallian ordinary demand function, consumer surplus (CS)[3] can be calculated as the following equation by applying the approximation suggested by Alexander et al. (2000):

$$CS = \frac{-P_{D1}Q_1}{2\alpha}$$

where α is price elasticity.

The total CS, as calculated in Table 7, is 947.46 million USD, which is 66% of the CV. The CS per unit is 78.40USD/Gcal, and the economic

Table 7
CV and CS for new heat consumers.

	Hicksian CV	Marshallian CS
Heat sales (Gcal): A	12,084,818	12,084,818
Average sales price (USD/Gcal): B	67.42	67.42
A × B (Million USD): C	814.82	814.82
Price elasticity	−0.433	−0.433
CV, CS (Million USD): D	1429.51	947.46
CV, CS per Gcal (USD): D/A	118.28	78.40
Total Economic Value (Million USD): E = C + D	2244.43	1762.29
Economic Value per unit (USD): F = E/A	185.71	145.82
Ratio of Economic Value per Price: F/B	2.75	2.16

[2] Correlation coefficient between Heat sale and GDP is −0.10441, meaning that one 0.1% decreases as the other increases 1%. Correlation between two variable seems less strength (Correlation between Sale and GDP is the same as the correlation between GDP and Sale).The Purpose of our study is to know how much heat demand changes with given change of GDP; GDP causes heat demand, not heat demand causes GDP.

[3] The consumer's surplus(CS) is a concept introduced by Marshall, and is equal to the difference between the amount of money that a consumer actually pays to buy a quantity of a good and the amount that consumer would be willing to pay for this quantity.

Table 8
CV for consumers with heat replacement.

	P_IQ_0 is 14% higher than $P_{D1}Q_1$	P_I is 20% higher than P_{D1}
Heat sales (Gcal): A	12,084,818	12,084,818
Average sales price (USD/Gcal): B	67.42	67.42
A × B (Million USD): C	814.82	814.82
Price elasticity	−0.433	−0.433
CV (Million USD): D	200.13	187.55
CV per Gcal (USD): D/A	16.56	15.52
Total Economic Value (Million USD): E = C + D	1014.95	1002.37
Economic Value per unit (USD): F = E/A	83.98	82.94
Ratio of Economic Value per Price: F/B	1.24	1.23

value that combines the price per unit and the CS is 145.82USD/Gcal. The difference in the estimated values between CV and CS is due to the difference in the denominators in equation. A higher price elasticity will result in higher CV, whereas a smaller price elasticity will result in higher CS. Theoretically, if the price elasticity is about −0.3334, the two will be equal.

The benefit for the existing consumer who switches from individual heating to district heating is calculated in equation (9). For this, we need to have information about the demand and prices of individual heating, namely, the consumer's demand for and the price of individual heating when there is no district heating. Thus, in practice, it is difficult to obtain the precise data. There is a lot of controversy over price competitiveness between district heating and individual heating in Korea. While individual heating through the city gas company is thought to be more competitive than district heating[4] due to the facility investment costs and the ability of consumers to control maintenance fees, district heating is considered to have the advantage of economy of scale through its large-scale supply. The cost of individual heating used to be higher than that of district heating, but, with recent low natural gas prices and differences in natural gas tariff setting methods (i.e., CHP is applied to wholesale charge and individual heating is applied to retail charge), individual heating prices have recently been shown to be lower than district heating prices.

Despite such controversy, many believe that district heating is better in terms of cost-effectiveness. Referring to data provided by Korea's Chuncheon Energy[5] company to infer the values for P_IQ_0, a comparison of district heating and individual heating shows that individual heating costs 14% more. Another way to estimate CV from the replacement effect is by estimating the change in demand using price elasticity in the district heating prices. This method is applicable in equation (11) and was used by Brynjolfsson et al. (2003):

$$CV = \frac{P_I Q_0 - P_{D1} Q_1}{1+\alpha} = \frac{(1+\varnothing)P_{D1}(1+\varnothing^*\alpha)Q_1 - P_{D1}Q_1}{1+\alpha} \quad (11)$$

where $\varnothing$ is the ratio of the change in price and $\varnothing^*\alpha$ is the change in demand resulting from the change in price.

Assuming that individual heating costs 14% more, the CV that results from switching to district heating is 200.13 million USD in total and 16.56USD/Gcal per unit (see Table 8). This is about 14% compared to the consumer's CV that results from the new demand. If all households with heat demand switch from consuming individual heating to district heating, the economic value of the whole country would be 1014.95 million USD. The ratio of economic value per heat price would be 1.24, meaning that the consumers who switch to district heating will receive an additional 24% benefit.

Assuming that the price of individual heating and district heating is the same,[6] than equation (11) is defined as follows $CV = \frac{P_{D1}(Q_0 - Q_1)}{1+\alpha}$. For new consumer, Q_0 is zero because it is a new customer who has never used heat in the past and this CV is than equal to equation (8). For switching customer, Q_0 and Q_1 can be the same or different. In case district heating and individual heat are the homogeneous goods, the rational consumer will use the same amount of heat under the same prices. When two goods are not homogenous for switching customer due to different heat use efficient and facility investment costs, the conversion customer's CV can be calculated by multiplying the district heating price by the difference in heat usage from the replacement. However, in this study, it is difficult to calculate the CV on the assumption that the two products are heterogeneous. This is because the CV by Brynjolfsson et al. (2003) method uses only price elasticity from estimated district heat demand function and district heat sales data, and there is no individual heating consumption data of consumers at the same price levels.

Assuming that the price per unit of individual heating is 20% more expensive (i.e., $\varnothing$ is 0.2), individual heating generates a decrease in demand of about 8.66% (i.e., $\varnothing^*\alpha$ is 0.086), according to equation (11). The CV based on this is 187.55 million USD in total and 15.52 USD/Gcal per unit.

The results of the increase in the national benefit from the introduction of district heating from equation (6) are demonstrated in Table 9. The national benefit is evaluated under the assumption that consumers switch from individual heating to district heating. We apply price and income elasticities of −0.43 and 0.92, respectively, along with a 14% higher cost in individual heating. For national income, the GDP in 2016 is used. As of 2016, the national benefit from the change in heat demand after the IES is calculated to be about 200.14 million USD, very similar to the estimated value in Table 8. The benefit per unit is 16.56 USD/Gcal; there is about a 24% additional benefit compared to the heat price per unit if a consumer switches to district heat.

When calculating the national benefit, if the revenue from heat sales does not account for a large portion of the national economy, the impact of GDP is minimal. As GDP accounts for 0.06% of the heat revenue as of 2016, most CV changes are affected by price elasticity. In the price elasticity sensitivity analysis, as the value of elasticity becomes inelastic, the CV decreases. This is due to the difference in the denominator of the equation. When price elasticity is small, the denominator approaches one and when the elasticity approaches unit elasticity, the denominator approaches zero. As shown in Table 9, as the price elasticity changes from −0.1 to −0.9, the CV increases about nine times, from 126.75 million USD to 1141.35 million USD.

4.3. Consumer benefit from IES electricity production

The IES business produces heat and electricity simultaneously through CHP. While producing electricity has been considered to be ancillary for the heat supply, its importance has grown due to Korea's expansion policy for dispersed generation. Electricity is an indispensable energy source for industrial production, household appliances, cooking, and lighting, and its value is in the benefit gained through its usage. The electricity produced from IES is used for processes in industrial complexes or sold to Korea Electric Power Corporation to be

[4] According to internal study by the Korea City Gas Association in 2016, district heating and individual heating prices were analyzed on the condition of comparison between the usage of energy in the same day and the average usage by heating method, and the relative price of individual heating is 14–26% lower than district heating. Source: www.e2news.com/news/articleView.html?idxno=96635.

[5] This company supplies community energy in Chuncheon, Korea and produces heat and electricity using LNG.

[6] With the valuable comments from reviewers, it is necessary in the future study to estimate the CV as consumers switch heat demand, assuming district heating and individual heating are heterogeneous products.

Table 9
National welfare effect from district heating supply.

	CV	Sensitive Analysis for CV from Price Elasticity	
Heat sales (Gcal): A	12,084,818		
Average sales price (USD/Gcal): B	67.42	Price Elasticity	CV(Million USD)
A × B (Million USD): C	814.82	−0.1	126.75
Price elasticity	−0.43	−0.2	142.60
Income elasticity	0.92	−0.3	162.97
P_1Q_0 is higher than $P_{D1}Q_1$	14%	−0.43	200.14
GDP (Billion USD)	1300.95	−0.5	228.17
CV (Million USD): D	200.14	−0.6	285.22
CV per Gcal (USD): D/A	16.56	−0.7	380.31
Total Economic Value (Million USD): E = C + D	1014.97	−0.8	570.52
Ratio of Economic Value per Price: E/C	1.24	−0.9	1141.35

Table 10
Consumer's CV for the electricity from CHP.

	Housing	General	Industrial	Total
Ratio (%)	13.7%	21.9%	56.1%	91.7%
Electricity Sales (MWh): A	1,046,043	1,672,142	4,283,432	7,001,617
Unit price (US cent/kWh): B	10.47	11.23	9.22	9.89
Electricity Sales Profit (Million USD)	109.53	187.90	395.34	692.78
Price elasticity	−0.332	−0.263	−0.263	−0.273
CV (Million USD): D	163.97	254.95	536.42	955.35
CV per kWh (US cent): E = D/A	15.67	15.24	12.52	13.64
Economic Value per kWh(US cent): F = E + B	26.14	26.48	21.75	23.45
Ratio of Economic Value per Price: F/B	2.50	2.36	2.36	2.38

resold to consumers. Electricity is consumed through the following purposes: housing, general, industrial, educational, agricultural, street lighting, and night lighting. Among them, housing, general, and industrial purposes account for 91.7% of total demand (see Table 10).

The benefit from the electricity that IES supplies is estimated using the sales data from the Korea District Heating Corporation that produces and sells electricity to Korea Electric Power Corporation and industrial complexes; the electricity for housing, general, and industrial purposes is evaluated.

As of 2016, the electricity produced by the Korea District Heating Corporation was 7670 GWh, and the electricity provided for housing, general, and industrial purposes, excluding internal consumption, was about 7000 GWh. The industrial purpose accounted for 4283 GWh, or 56.1% of the total; the general purpose for 1672 GWh, or 21.9% of the total; and the housing purpose for 1046 GWh, or 13.7% of the total. The average consumer cost of electricity was 9.89 US cent/kWh. The electricity for general purpose was the most expensive at 11.23 US cent/kWh, and electricity for industrial use was the cheapest at 9.22 US cent/kWh. Korea District Heating Corporation's profits from the sale of electricity to consumers through the Korea Electric Power Corporation was 692.78 million USD.

The price elasticity to calculate the benefit of electricity production was not estimated separately here; instead we included previous research data on electricity price elasticity for each purpose in Korea. The estimated average value of the price elasticity of electricity for general purpose was −0.332 and for general and industrial purposes, it was −0.263.

Because electricity is mostly a non-replaceable energy source, except in limited cases such as cooking, it is reasonable to evaluate the consumer benefit in the point of the introduction of a new electricity source rather than of the concept of switching to another energy source. The CV for the electricity supply averaged around 13.64 US cent/kWh, and the CV for housing was the highest among the purposes at 15.67 US cent/kWh. The economic value that combined the CV per unit and electricity cost averaged around 23.45 US cent/kWh, and a consumer using a single unit of electricity was evaluated to have 1.38 times additional benefit.

5. Conclusion and implications

IES is the business of supplying heat or heat and electricity by producing heat and electricity simultaneously. It is more efficient than producing heat and electricity independently because the heat generated from the process of producing electricity through CHP facilities can be supplied to consumers.

For consumers, the heat supply using IES provides benefits: by installing large-scale facilities in accordance with local demand for heat, it can reduce the annual heat cost compared to individual heating systems through lower facility costs. The Korean policy makers need information on the benefits of providing district heating service in the region. However, research on the consumer benefits has been limited, and, to date, the CS has been calculated based on the ordinary demand function. For heat demand, as it includes not only new consumers but also existing consumers who switch from individual heating to IES, it needs to be analyzed through the replacement concept.

This study estimates the CV following the method of Hausman and Leonard (2002). The new consumers receive CV of 118.28 USD/Gcal per unit for using district heating from the IES supply and gain an additional 1.75 times benefit even after paying for the use of heat. The economic value of district heating for such consumers combines the price per unit and CV at 185.71 USD/Gcal.

In the case of existing consumers who switch from individual heating to district heating, it is difficult to obtain precise data on consumer demand and prices for individual heating if there is no district heating. Under the assumption that the district heating is 14% cheaper, the result in previous studies, this study calculates the CV based on heat replacement. The result shows that the CV from switching to district heating is 200.13 million USD in total and 16.56 USD/Gcal per unit. The ratio of economic value per heat price is 1.24, indicating that a consumer would receive an additional 24% benefit from switching to district heating.

The consumer benefit from producing electricity and heat simultaneously through the CHP facilities takes into account electricity for housing, general, and industrial purposes; the CV is estimated at 13.64 US cent/kWh. Because electricity is mostly a non-replaceable energy source, except in limited cases such as cooking, the consumer benefit from the supply is evaluated by considering the benefit from the introduction of a new electricity source, namely, IES, rather than from the concept of switching to another energy source. The economic value that combines the CV per unit and electricity cost average of 23.45 US cent/kWh and a consumer using a single unit of electricity is evaluated to have 1.38 times additional benefit.

The estimation of the consumer benefit based on demand functions relies heavily on price elasticity, regardless of whether the method uses the CS or CV. According to the calculation, a higher price elasticity will result in a higher CV, whereas a small price elasticity will result in a higher CS. Theoretically, if the price elasticity is about −0.3334, the two will be equal. This study shows that the CV is greater than the CS. Typically, the district heating demand is a utility good and is not, therefore, very sensitive to price; as national amenities improve as a result of increased income, the heat demand becomes inelastic to price. The heating price elasticity of −0.433 in this study is less elastic than −0.7 estimated in a previous research,[7] however, it is still high considering the price elasticity of electricity is between −0.2 and −0.3.

[7] Korea District Heating Corporation (2015). Estimation service for community energy business benefit.

The study shows that the expansion of district heating through integrated energy supplies in Korea can not only improve energy efficiency but also be a useful policy tool for coping with climate change, and can increase consumer welfare.

However result of this study the need for further research. First, various values of price elasticity can be estimated according to different methods and the resulting consumer benefits may be different. It is, thus, necessary to obtain additional data that would stabilize the estimated value or to develop a heat demand function that can generalize the value. Second, it is necessary in the further study to estimate the CV as consumers switch heat demand, assuming district heating and individual heating are heterogeneous products. Nevertheless, this study is meaningful in that it estimates the consumer benefit from district heating as a result of IES.

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